Every day, Americans pump 82.3 billion gallons of groundwater from stony subterranean basins, or “aquifers,” that underlie enormous parts of the United States. Eighty-two billion gallons fill a swimming pool the size of California and Indiana combined. Groundwater is essential to many public, agricultural, and industrial uses: We drink the water, wash in it, maintain domestic animals and irrigate crops with it, and use it in factories and refineries. Californians alone extract nearly 20 percent of the groundwater used in America. Among the hydrologists who study our nation’s groundwater supply is SF State geosciences professor Dr. Jason Gurdak. A colleague who studies surface water once described Gurdak’s subject as “voodoo” because of the hidden and intangible nature of underground water. Nevertheless, Gurdak’s research helps safeguard the purity and availability of a precious resource that is threatened by overuse and contaminants, and whose volume may be shrinking as our global climate heats up.

The United States overlies 50-some aquifers of different sizes, from the massive High Plains aquifer in the Midwest to the much smaller coastal aquifers beneath California. The High Plains aquifer, known in the Central States as the Ogallala aquifer, totals 174,000 square miles. That makes it slightly bigger in area than our own state of California (163,500 square miles). Aquifers are composed of loosely compacted sediments such as sand, gravel, clay, and rock,
including sandstone, limestone, and fractured granite. The porous nature of sediment and rock allows rain and snowmelt to infiltrate the soil and flow as groundwater, then collect in aquifers that act much like giant sand boxes or basins. California has a number of important aquifers, including the Central Valley aquifer, California Coastal aquifer system, and the Basin and Range aquifer system.

Many of California’s aquifers, especially the crucial Central Valley aquifer and the Coastal aquifer system, provide water for irrigated farmlands and large population centers. These and other aquifers have become increasingly depleted, however, as people pump out and use groundwater faster than it can “recharge.” As Gurdak explains, this recharge process—the refilling of an aquifer with groundwater—depends on the rate at which rain, snowmelt, or irrigation water from farmlands reaches the water table.

How water and associated chemicals flow down through the ground to reach an aquifer is a major concern for “hydrogeologists,” or groundwater hydrologists. This is why much of Gurdak’s research focuses on the “vadose zone” or unsaturated zone. The vadose zone is the rock and sediment lying between the land surface and the water table of an aquifer that is not saturated with water. Water must trickle down through this vadose zone to the water table in order for the groundwater in an aquifer to be recharged.

The vadose zone is crucial to the recharge process because so many different variables affect the flow and chemical content of groundwater as it passes through this unsaturated layer. Numerous factors—from agricultural and urban land use, to soil and rock types, to changes in weather and climate—can potentially influence groundwater as it passes through the vadose zone.

Gurdak, who moved to California from Colorado, noticed a major difference between the local vadose zone and such zones to the East. “The further west you
go," he says, "because it's more arid, the more that zone increases in thickness. You don't get as much water moving down through the zone, so it becomes really important to understand the processes" of downward movement.

Although Gurdak is now one of a relatively small number of American hydrogeologists studying vadose zones, he did not grow up dreaming of the day when he would sample water tables and study groundwater vulnerability. Not until he took an introduction to geology class did he discover an interest in Earth and its water supply. Already a passionate outdoorsman, Gurdak decided to pursue his newly discovered interests at the Colorado School of Mines. There he earned a Master's degree in environmental science and engineering and a Ph.D. in geochemistry. “I really like the altruistic nature of working in hydrology because you can see how it benefits society,” said Gurdak, discussing his motivations for studying hydrogeology. This appreciation for the civil applications of hydrogeology would also lead Gurdak to spend a decade stationed in Colorado and working for the U.S. Geological Survey (USGS).

During those 10 years, Gurdak primarily studied the High Plains aquifer, which underlies parts of eight states and stretches from South Dakota to the Texas panhandle—one of our nation’s largest agricultural economies. The High Plains aquifer provides 82 percent of the drinking water for the local residents. It has been the water supply critical to transforming this region into its current agricultural importance. He designed his USGS studies to probe the processes that affect groundwater quantity and quality in the High Plains aquifer. He and coworkers installed hundreds of wells in the aquifer so they could extract and monitor the groundwater.

Gurdak sampled these wells, analyzing the water’s chemical content, including hazardous compounds. “The big concern is nitrate,” says Gurdak. “It’s a nutrient, so it’s good for plants, but in elevated concentrations in the water that we drink, there are health concerns. It’s been linked to different types of cancer as well as spontaneous miscarriage in women.” In response, the U.S. Environmental Protection Agency has created a legal drinking water standard for nitrate in public drinking water. Testing and applying this standard to groundwater helps resource managers know where the groundwater is safe to use in various applications. Luckily, as Gurdak has discovered, some of the nitrate degrades before penetrating into the water table. The degree of pollution ultimately depends on the vadose zone and its innate filtering capacity in any particular area.

Nitrate comes from many sources, and surprisingly, not all nitrate in groundwater originates in human activity. It can be a by-product of commercial fertilizers and animal manure. Rain and snow can also wash down airborne nitrogen compounds produced by industry and automobiles. And natural soil processes form nitrate. “In the West,” Gurdak explains, “over hundreds to thousands of years,” rainfall has carried chemicals down to the land surface where it dries and leaves behind salt deposits. “Over
time,” he continues, “very large nitrate and chloride reservoirs can form right below the surface.” When people disturb the climate or use the land, typically by converting natural grassland to irrigated farmland, these chemical reservoirs are mobilized. Once the chemicals reach the water table and disperse throughout groundwater in aquifers, the nitrate concentrations can increase to alarming levels.

Although Gurdak enjoyed his fieldwork, he left the USGS and moved to California in August 2009, to begin teaching and conducting research as an assistant professor in the SF State Department of Geosciences. Gurdak is highly motivated to share his insights and spread his knowledge of hydrogeology with students. “I feel most challenged and inspired in an academic environment,” he says, “where I have freedom with the direction of my research to become the scientist that I aspire to be.” He is also passionate about “helping the next generation of scientists gain the experience that they’ll need to address some truly unprecedented problems related to climate change and water resources.”

Two of Gurdak’s students were recently accepted into prestigious research programs at the National Science Foundation and NASA Ames Research Center to study water-resource issues in New York and California. Gurdak takes his students on field trips to the coast and local wells so that they can practice measuring and monitoring groundwater conditions.

In Spring 2010, this writer had the opportunity to accompany Gurdak and his Environmental Geology class on a field trip to San Francisco’s Ocean Beach. There, the 20-some students observed and discussed interesting coastal processes that, in their own way, confirm global warming. The field trip took place on an overcast afternoon in early May afternoon, and strong gusts of wind sent a low-lying fogbank drifting in from the ocean. Gurdak led the group to a black-sand area that looked unnatural from a distance—as if an oil spill had covered the beach. The class soon discovered, however, that the black grains were particles of the magnetic mineral magnetite. After describing some of the area’s coastal landforms, including the San Francisco sandbar and continental shelf, Gurdak began to explain its geologic history.

Some 20,000 years ago, during the peak of the last Ice Age, sea level was 400 feet lower than it is today and the shoreline was 19 miles west of its current position beyond the Farallon Islands. For millennia, Gurdak explained, massive quantities of water have been trapped in the world’s glaciers. With global temperatures rising, however, these glaciers have been melting and slowly raising the sea level. This geologic-scale glacial melting of the glaciers has been accelerated by recent human activities such as the release of carbon dioxide into that atmosphere and subsequent warming of the planet’s surface.

Climate change and rising sea levels worry hydrogeologists because as the levels rise, more and more salt water infiltrates coastal aquifers and contaminates the fresh water. Because coastal regions support so many of Earth’s major population centers, the purity of these coastal aquifers is vital—and threatened.

At Ocean Beach, Gurdak and his students dug a hole in the sand in search of groundwater from the Westside Basin aquifer, an important local aquifer beneath the city of San Francisco. After digging for several minutes, they struck the water table at a depth of 2.5 feet. They collected both ocean water samples and freshwater samples from the bottom of the hole. Next, Gurdak measured the conductivity of the two samples and compared the results to that of water sampled from a faucet in Thornton Hall. Measuring conductivity essentially determines the concentration of dissolved solids (or salts) in the water. Gurdak’s demonstration revealed that the conductivity of the ocean water far surpassed that of the tap water (as expected). The groundwater’s conductivity, however, was approximately half that of the ocean water, indicating a mixing
of salty ocean water and fresh groundwater. Telltale signs such as this show that climate change may be affecting our planet’s water resources at a far faster rate than most experts predict.

As the debate about climate change intensifies, the questions surrounding global warming and groundwater have grown more important. Studies of the vadose zone have revealed not just rate-of-change data but also how climate variability influences groundwater movement. “Climate influences groundwater through the vadose zone,” says Gurdak, “so if you’re interested in climate variability, climate change, or just weather, it has to go through this zone.” Analyzing data from the vadose zone is tricky, however, because processes occurring in the subsurface could be the result of natural events from the past. “We have to think like a geologist and go back in time, maybe hundreds or thousands of years, to understand how climate has changed and how that’s affecting water and chemical movement.”

Natural climate cycles such as El Niño or La Niña affect a region’s precipitation, creating a consistent correlation between these long-term patterns and groundwater levels. The public is much less aware of longer climate cycles that recur over many decades, including the Atlantic Multidecadal Oscillation and the Pacific Decadal Oscillation. These extended cycles, Gurdak explains, each have a wet phase and a dry phase that influence precipitation in different parts of the U.S. Changes in a region’s precipitation also speed or slow the recharge rate of the local aquifer. When the dry phases of different climate cycles align in a specific way, the effect can be quite severe. The overlay of such patterns, Gurdak says, may help explain the widespread U.S. droughts of the 1950s and before that, the 1930s (leading to the Dust Bowl).

Gurdak plans to create a complex forecasting system using climate change and variability to predict how certain aquifers in the U.S. will recharge in the future. “We’re taking the forecasted precipitation over the next 50 to 100 years,” said Gurdak, “and putting them into computer models of hydrogeology and trying to simulate how future climate change might affect the recharge of aquifers.” With such information, hydrogeologists will be able to answer questions about society’s use of groundwater. “We’d like to be able to make statements that: If we’re in a given phase of one of these cycles, are we going to be getting more or less recharge in the High Plains? More or less recharge over in the Central Valley?”

Dr. Gurdak’s Hydrogeology class (Geol 475/775) sampling a well near campus.

Right and left photos courtesy of Dr. Gurdak, middle photo courtesy of Amber Kuss, Geoscience MS student.